Computer-supported simulations for urban planning

Model calculations for visualizing the dynamic process of city-development using an example of a transportation system

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Abstract

The idea about a simulation program to support urban planning is explained: Four different, clearly defined developing paths can be calculated for the rebuilding of a shrinking town. Aided by self-organization principles, a complex system can be created. The dynamics based on the action patterns of single actors, whose behaviour is cyclically depends on the generated structure. Global influences, which control the development, can be divided at a spatial, socioeconomic, and organizational-juridical level. The simulation model should offer conclusions on new planning strategies, especially in the context of the creation process of rebuilding measures. An example of a transportation system is shown by means of prototypes for the visualisation of the dynamic development process.

1. Introduction

The infrastructure issue is most complicated in urban planning. Infrastructures in this case are for example all care institutions of a city like streets and public transportation-systems as well as supply networks for water, steam, gas, phone etc. In addition, public access to certain functions is also a part of this infrastructure. That might be public institutions like schools or hospitals, or shops that deliver goods, as well as enterprises, that provide workplaces. These supplying functions are defined as centres. The system's infrastructure and the physical visualization of spatial unities are varying and are interwoven radically with the different levels of the whole structure. Every section has its own, extremely individual problem that has to be taken into consideration (catchments area, profitability calculations, swells of dimension, etc.). Difficulties of gradual adaptation to the dynamically changing demographic and socioeconomic conditions arise. This happens in public as well as in private-economic infrastructure. Hence it seems advisable to introduce a practically oriented, computer-supported urban simulation-model, which is capable of illustrating essential parameters of urban development for a concrete case and therefore provides a basis for the simulation of different scenarios. To achieve this city has to be abstracted in three essential levels: the spatial, the socioeconomic and the organizational-juridical level. The complex relations between spaces, actors and instruments must not only be well human readable, but the changes of the simulation in time must be traceable. Own attempts and experiments on generative, control-based structural processes (Fig. 02) opened multi-layered perspectives for the development of a new generation of complex city models.

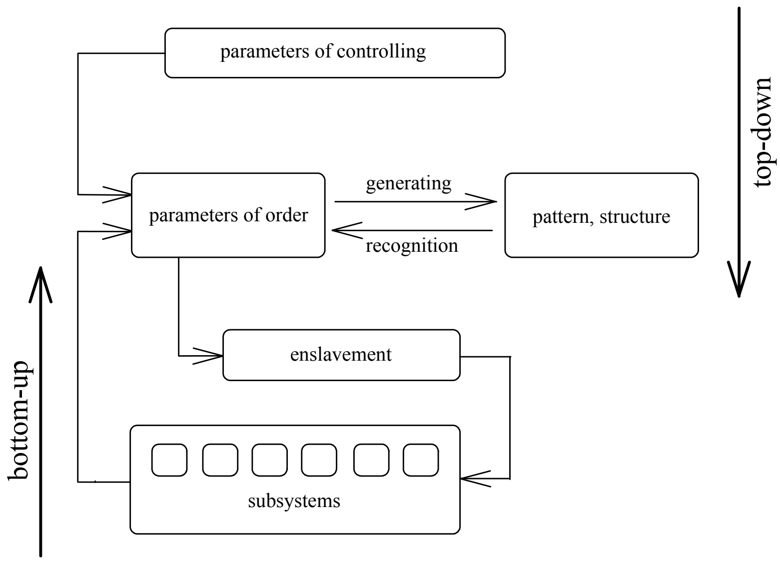

Fig. 01: The principle of synergetic, bottom up und top-down. [Wunderlin 1996]

2. Conceptual formulation

The basis of the work is a system-theoretical model, which divides the complex system of a city into its essential elements. These elements have different qualities according to the degree of abstraction, scale and working task. By defining those elements, both their relations and the borders of the system have been fixed. Thereafter, the principle of self-organization orders the elements in a bottom-up procedure. This means that there are no given patterns, but the elements influence themselves (because of their own qualities and generated behaviours) in a way such that a complex structure is generated. For this reason not all urban processes can be simulated. Restrictions on different levels must be introduced to control the system on a global level, also known as top-down procedure (Fig. 01). The different phenomena of an urban structure are implemented by using mathematical descriptions from urban theory. By the adaptable combination of both principles, top-down and bottom-up, the process is simulated under changing conditions.

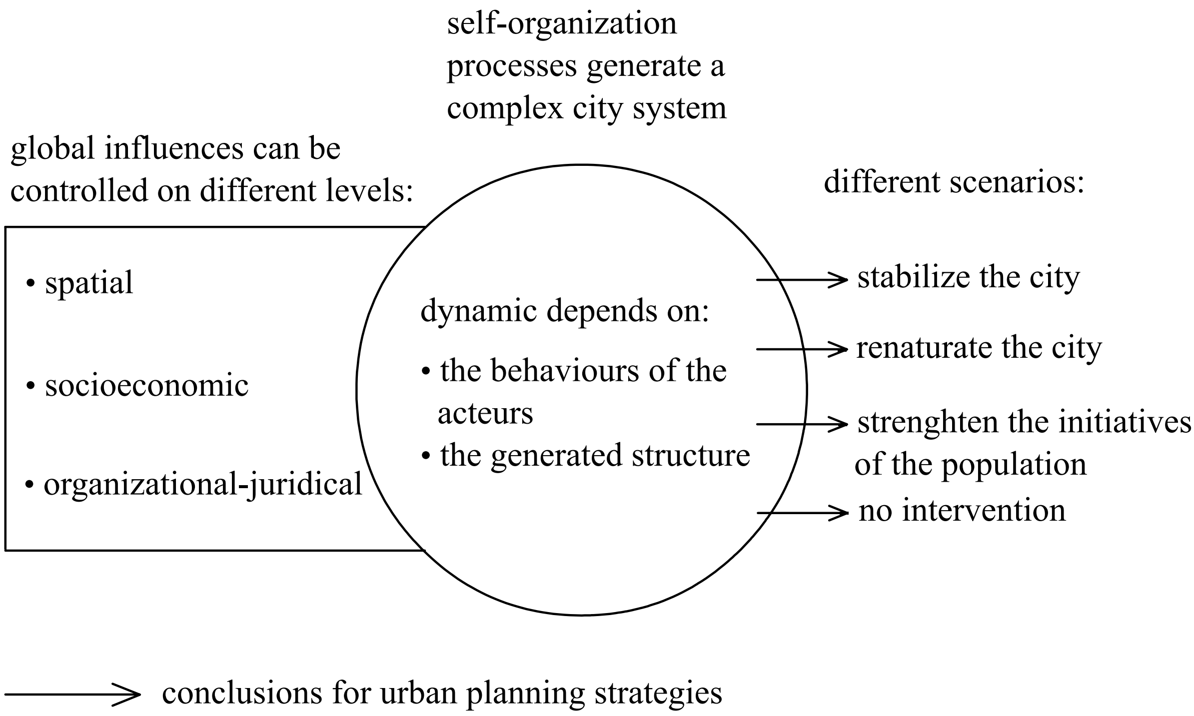

Fig. 02: Method of simulating the development of the city.

3. Description of the IRN principle

The implementation of the above simulating concept necessitates a relatively high spatial resolution of the simulation models in order to capture the time dependent dynamics of individual and collective actors. These concepts are being simulated with the support of new results from biological sciences on the behaviour of complex, self-organizing ecosystems and via new mathematical models from disaster-, or chaos theory, the theory of cellular automata (CA) or multi-agent-systems (MAS) which can now represent individual as well as collective urban actors. Individual actors, for example, are the single inhabitant or a political decision maker. A collective actor is, for example, an interest group or an institution. A system that consists of both CA and MAS components is known as ‚Free Agents on a Cellular Space'(FACS) [Portugali 2000]. The interaction of CA and MAS results in an `Inter Representation Network'(IRN), which expresses the inter-dependence of both components. The following examples are based on these fundamental concepts. Based on this theory, more complex representations of urban processes are being developed.

4. Example of a public transportation-system

For an introduction demo of the IRN principle the interaction of the transportation system with its users is treated. This investigation serves to identify the elements and parameters which are necessary and essential for the self-organisational structure. Three computer simulations are described that become gradually more complex.

4.1 Basic model

Input / Interface

A certain number M of movable agents Am, m = 1, 2, …, M, is being distributed onto random positions j within the cellular resolution:

$$A_j^m = \text{random}(j)$$

Mathematical representation

For the random walk we have: The values of the movement vector (Heading H) varies within the "Angle Threshold" Φ either to the left (-) or to the right (+).

$$H_A(t+1) = H_A(t) + \text{random}(\Phi) + \text{random}(\omega);$$

The „Wiggle Angle“ ω states the random deviations of the movement vector from the chosen direction.

If a mark (signpost) turns up in the field of vision of the agent, it follows dependent on the adjustment of the software, the strongest mark (signpost):

$$H_A(t+1) \Leftarrow \min_j \; Pj(t);$$

or, alternatively, weights the probability for the next step.

Description

The agents move in randomly chosen directions across the cellular grid (random walk.

The distance which an agent can cover per unit time amounts to one cell in the Moore neighbourhood. When a cell is crossed, the agents drop marks (signposts), comparable to the chemical pheromone traces with ants. If, in the process of the random walk, one or more marked (signposted) cells are met within the field of vision (angle threshold) of an agent, it follows this mark (signpost). For the decision, which mark (signpost) the agent ought to follow, two procedures are available. In the first one, the so called "hill climbing", the agents follows the strongest mark (that one with the highest value). The second procedure is known as "roulette wheel" and weighs the probability in the selection of a cell according to the

strength of the mark in question. The marks decay then gradually with time. Visually, the mark values of the cells are represented using a scale of gray values. Through the interaction of the agens with the cells a self organizing path system is generated. The resulting structure can be regarded as a type of reservoir. The agents communicate indirectly across the coloured cellular grid, which determines their directional movement. Through the agents use of the system it is preserved. The patterns are dependent on the adjustment of the parameters, but remain stable over larger time periods, once the system has targeted a single structure.
If then the parameters are changed, an adopted pattern gradually arises. For instance, the decay rate of the markings (in model 4.2 and 4.3 evaporation rate) defines the 'density' of the path system, dependent on the strength of the marking. In a sense these two parameters can be regarded as the available building material or capital, which can be used for the building and maintenance of the system. Accordingly, some links are abandoned or introduced, if these values are varied.

Graphical output

Fig. 03: Structures based on the roulette wheel selection with the following values (starting top left to bottom right):

M = 100, angle thresh = 23, wiggle thresh = 0, after 170 timesteps
M = 100, angle thresh = 30, wiggle thresh = 0, after 4000 timesteps
M = 100, angle thresh = 68, wiggle thresh = 5, after 1500 timesteps
M = 100, angle thresh = 60, wiggle thresh = 60, after 7000 timesteps

Control parameters

As a result of the constant cellular grid the relevant values for the angle threshold amount to 22,5 | 67,5 | 112,5 | 147,5. If one falls short of these values or exceeds these values then two neighbouring cells drop out of the field of vision of the agent or, alternatively, two cells are added. If the hill climbing procedure is being initialised with an angle threshold = 68 and an wiggle angle = 0, then small separate clusters develop. If the valued for the wiggle angle is increased, connections between the clusters start to evolve. The system behaves similarly with the roulette wheel. Setup is at an angle threshold = 113, where the value is subsequently decreased.

Kernel algorithm

Suppose the fitness of N individuals in a population is: f1, f2, f3... fN.
In roulette wheel selection, the probability of an individual being selected is
Pi = fi/(f1+f2+...+fN).

Then a parent is selected by going through the following steps:

a) Generate a random value r between 0 and 1.
b) Set sum = 0;
c) for i=1 to N do

```
begin
   sum = sum + Pi;
   if (sum >= r)
   return i;
end
```

Further work

The cellular grid does not necessarily have to be organised in a rectangular manner. Any geometry that can be defined is possible. For instance, a triangular separation is possible [Schweitzer 2003].

URL of the program

http://www.entwurfsforschung.de/Strukturfor/delphi/delphiF.htm#path01

References

SCHWEITZER[2003]
BATTY[2005]

4.2 Model with sources and target

Input / Interface

Starting with the basic model from 4.1 ten randomly distributed starting locations (home cells) for the agents plus one central location (centre cell) in the middle of the field is defined. In the beginning the agents are evently distributed onto the home cells.

Description

As long as the agents have not yet discovered a centre cell (or a path mark/sign post), they move across the field in a random walk. As soon as an agent hits a centre cell, he changes his inner condition and attempts to get back to its home cell as quick and effortless as possible. After his way back the agents drops a marking at the cells which he crosses. Subsequent agents now attempt to follow these markings on their way home (to save costs). These markings are also used by agents who still (or again) search for the centre cell. The path finding algorithm for the determination of the direction of movement of an agent on his way home is complemented in the following way: Before the hill climbing starts the agent is directionally adjusted (heading H) towards the home cell, whose coordinates he memorizes and continuously compares with his current position. A network of home cells and centre cells evolves, whereby the home cells often connect directly with each other, even though they do not always keep a direct connection to the central location. After initial fluctuations a relatively stable path structure evolves which changes only minimally with longer time periods and which is comparatively resistant to disturbances from outside (mouse interaction).

Graphical representation

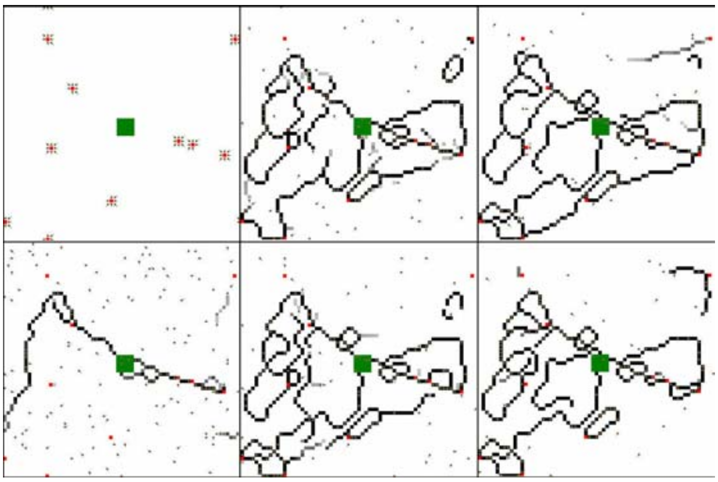

Fig. 03: Shown is a path system (Hill Climbing Selection) with parameters M = 200, angle thresh = 45, wiggle thresh = 25 with timesteps (starting top right to bottom left) 2, 200, 1.000, 4.000, 10.000, 20.000.

Control parameters (Interpretation of institutional applications)

In order to achieve path connections, the crucial parameters are Angle Thresh and Wiggle Thresh. With the parameters pre-adjusted, in most cases a number of 400 cells are necessary for a stable path system (see the graph with high visibility threshold).

Further work

Internal value (energy resource) for the consumption (is less when path is used rather than generated). Introduction of land planning structures –> starting points of further agents, e.g. if a threshold is exceeded, the road remains intact and planning permission is given.
-> competition between good locations with sufficient space for roads ! -> density of the road use <-> space requirements/jam

URL of the program

http://www.entwurfsforschung.de/Strukturfor/delphi/delphiF.htm#path02

References

SCHWEITZER [2003]
BATTY [2005]

4.3 Evolutionary Network

-> Evolution of the agent behaviour - the more rapid and the more energy efficient agents survive. If the path is crowded the agents move on to other/new paths.

Input / Interface

Starting off with the model 'Path System 02', it will be investigated, which values for angle threshold and wiggle threshold are most effective.

Mathematical representation

See the description

Description

Efficiency is measured in terms of the number of times the agent finds his way from his home cell to the centre cell forth and back. Every agent is equipped with a limited energy resource, which gradually decreases with the movements across the cell field. The use of streets (marked cells) requires less energy than the movement across the free field (empty cells). If the energy resource is used up, the agent returns/is reborn with a new breed of adjustments of the most effective agents in his `family' (= identical home cell). The path structure that the agents have generated and the movement parameters of the agents interact in a complex an reciprocal manner. The angle threshold and the wiggle threshold are optimised with a genetic algorithm. The above mentioned efficiency corresponds to the so called fitness function. The mutation rate is able to push the system out of the local minimum by randomly changing single parameters. Dependent on the arbitrary initial values for position and direction of the agent, a path system evolves, whose cellular net develops through the optimisation of the available energy resources.

Graphical representation

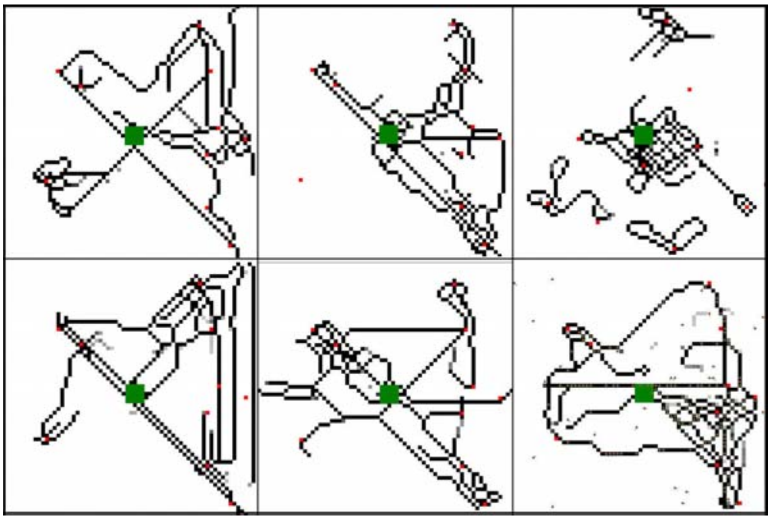

Fig. 03: Shown are six different structures which have developed after 50000 time steps. The position of the home and the centre cell do not vary. Bei den einzelnen Durchläufen haben sich jeweils andere Parametereinstellungen für „Angle Threshold" und „Wiggle Threshold" ergeben. In the simulations different parameters of angle threshold and wiggle threshold have evolved. Nevertheless, some structural elements of the different path systems repeat themselves.

URL of the program

http://www.entwurfsforschung.de/Strukturfor/delphi/delphiF.htm#evoNet01

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